

Controls on porphyroblast nucleation in high-grade metapelites

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Most rocks undergoing metamorphism are aggregates of minerals that provide a variety of nucleation sites for new minerals. At low grades, the nucleation and growth of new minerals is generally controlled by variations in reaction affinity related to local changes in composition inherited from the protolith. At higher grades of metamorphism, nucleation and growth is controlled by compositional heterogeneity due to the distribution of porphyroblasts produced by lower grade reactions. In this case, nucleation of new minerals is suppressed or enhanced by reaction affinities that are buffered by local reactions between the earlier formed porphyroblasts and surrounding matrix minerals. This is well illustrated by considering a pelite that successively crosses the garnet, staurolite and sillimanite isograds in an isobaric heating environment typical of regional- contact terranes.

In this situation, nucleation of garnet is typically controlled by overstepping of the reaction chlorite + muscovite = garnet + biotite. However, the temperature of this reaction is strongly influenced by the Mn content of the local environment, so that the first garnets are more likely to nucleate in regions that are more Mn-rich, because the reaction is overstepped at lower temperatures in these sub-domains of the rock. As heating continues, an increasing proportion of garnets will begin nucleating in more Mn-poor environments as the garnet-forming reaction is overstepped for those compositions. This phenomenon is accentuated by the suppression of garnet nucleation near the early formed garnets as they begin to grow and enlarge their equilibration volume in the rock.

The nucleation of staurolite is controlled by two fundamental reactions: the stable reaction garnet+chlorite+muscovite = staurolite+biotite in regions that have equilibrated with garnet and the meta-stable reaction chlorite+muscovite = staurolite+biotite in regions that have not equilibrated with garnet. At 4 kb, the metastable reaction is overstepped first, about 10 °C below the stable reaction for a typical pelite composition, suggesting the meta-stable reaction may be an important control on staurolite nucleation and growth in these environments. Commonly observed textures involving garnet and staurolite in regional-contact terranes support this hypothesis.

There are four reactions that control sillimanite nucleation. They are the stable reaction $\text{staurolite} + \text{muscovite} = \text{sillimanite} + \text{garnet} + \text{biotite}$ and three meta-stable reactions: $\text{chlorite} + \text{muscovite} = \text{sillimanite} + \text{biotite}$, $\text{chlorite} + \text{muscovite} + \text{garnet} = \text{sillimanite} + \text{biotite}$, and $\text{staurolite} + \text{muscovite} = \text{sillimanite} + \text{biotite}$. The first two meta-stable reactions are overstepped about 20 °C below the stable reaction for typical pelite compositions and the third meta-stable reaction is overstepped several degrees above the stable reaction for typical pelite compositions.

Sillimanite commonly nucleates in matrix biotite that is present in the local environments for all four of the sillimanite-forming reactions listed above. The primary controls on sillimanite super saturation and nucleation in these types of rocks are the local equilibrium reactions between preexisting porphyroblasts and matrix. Local equilibrium with staurolite buffers the activity of sillimanite to a very low level, so that biotites near staurolite are not typically sites of sillimanite nucleation. Local equilibrium with garnet and staurolite buffers the activity of sillimanite at only a slightly higher level than staurolite without garnet, so that biotites near staurolite + garnet are not commonly preferred sites for sillimanite nucleation. Local equilibrium with garnet (no staurolite) buffers the activity of sillimanite at a much higher level that is only slightly lower than the sillimanite activity in the garnet-free and staurolite-free meta-stable assemblage of biotite + chlorite + muscovite, which has the highest affinity for sillimanite formation. Thus, the most favorable sites for sillimanite nucleation are in matrix biotites that are isolated from both garnet and staurolite because the reaction affinity for sillimanite is highest in chlorite, biotite, muscovite, quartz assemblages that are not buffered by local equilibrium with staurolite or garnet. However, environments equilibrated with chlorite, biotite, muscovite, *and garnet* buffer the sillimanite activity at only a slightly lower level than the garnet-free assemblage, so matrix biotites near garnet (without staurolite) are also a likely site for sillimanite nucleation and growth. This provides an explanation why sillimanite segregations in thermally dominated meta-pelites tend to be located away from staurolite porphyroblasts, either in the matrix or adjacent to partially consumed garnets.